Evolutionary mismatch occurs when a trait that evolved as beneficial in one environment becomes maladaptive in another [1]. Natural selection constantly sculpts species, but when environmental change is too rapid or too extreme selection cannot keep up. The concept of evolutionary mismatch is especially important in the modern world because of the unprecedented rapidity and degree of anthropogenic environmental change, and our own species is facing increasingly novel environments, both physical and cultural [1]. Applications of the idea of mismatch to humans has been much discussed, especially concerning modern diet, but also certain other aspects of contemporary lifestyle, including lack of exercise, reduced sun exposure, sleep deprivation, chronic stress, etc. (e.g., [1-3]). However, the term mismatch can apply even more broadly to include many other aspects of modern societies, including mistreatment of women, child abuse, unequal distribution of resources, difficulty with long-term planning (e.g., lack of retirement planning, failure to address environmental problems such as climate change), and other current challenges.

These mismatches can have a variety of proximal or at least more direct causes including: a) supernormal stimuli; b) the vast difference between the modern social context and that of our ecological and evolutionary past; and c) the fact that our brains did not evolve to deal with certain situations. First, let us consider supernormal stimuli. This concept was developed by Tinbergen [4] and explored by various others including Barrett [5]. A classic example is a shorebird, the oystercatcher (*Haematopus palliatus*) (Figure 1). If presented with an egg much larger than its own, an oystercatcher will ignore its own egg and attempt to incubate the completely inappropriate one, which it could not possibly have laid. In the human context, junk and processed foods with unnaturally high concentrations of sugar and other refined ingredients, or those that are artificially colored can be more stimulating physiologically and visually than natural foods [5, 6].

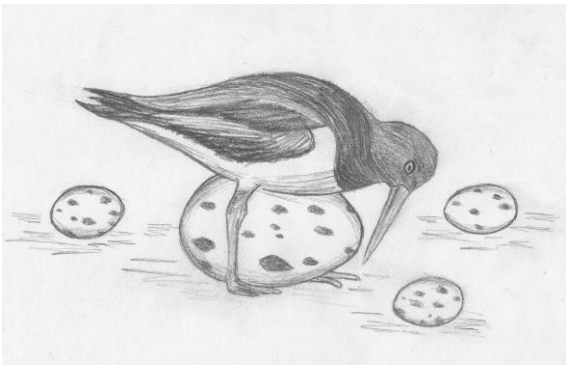

Figure 1. Oystercatcher. Drawing by Kerry Brock based on [4].

Our modern social contexts are also very different than those in which our species evolved. For example, in the modern world, there is an extraordinarily unequal distribution of resources. A recent headline proclaimed, "The 62 richest people have as much wealth as half the world" [7]. Likewise, the wealthiest 160,000 U.S. families are reported to own as much as the poorest 145 million [8]. Now consider an ancestral hunter-gatherer social environment. Band size varied, but 30 individuals is a reasonable number for the sake of discussion. Communication (including verbal, physical, and behavioral signals) between individuals in such groups was important in terms of sexual selection and crucial for both survival and reproduction (i.e., signaling theory; e.g., [9,10]). In a hunter-gatherer band, individuals who mistreated women, abused children, hoarded resources, or were otherwise anti-social would send the wrong signals. Mating opportunities, group status, reciprocity, and even continued inclusion in the group would all be compromised. There were clearly constraints on behavior in the pre-modern small group social

setting, and potentially severe consequences for anti-social behaviors. However, in the modern world our large population size, relative anonymity, and complex economic systems insulate individuals from effects of their greed or other bad behavior. This clearly seems to be an example of a mismatch.

Other mismatches, I argue, occur because our brain evolved to effectively solve relevant ancestral problems, but not to deal with novel modern situations. As a result, we harbor many innate cognitive biases. These largely unconscious biases worked for our distant ancestors in their environmental context, but are ill suited to novel modern circumstances. Wright [11] described people in the modern world as running 21st century software on fifty-thousand-year-old hardware. For example, like other primates we have neuronal pathways that bias us towards recognizing snakes (a clear danger in the ancestral context) [12], and we now often mistake sticks for snakes, but rarely the reverse [13]. This bias has little negative effect. However, other biases have broader implications that impact many aspects of our lives, and in some cases result in people making objectively irrational decisions with serious implications. For example, "discounting the future" is a bias that makes us more likely to value immediate rewards over future benefits. This was beneficial to hunter-gatherers (e.g., it was best to drink and eat while water and food were available). However, in the modern world the same bias results in spending too much now and not saving enough for later (e.g., for retirement). If an individual consistently invests a small amount of money, say $5 per day, in the stock market beginning at age 24, he or she will have $717,288.85 at the end of 40 years. This assumes an average 9% increase per year (which is below the long term 10% average gain of the U.S. stock market), and monthly compounding. Five dollars is the cost of the least expensive package of cigarettes in some areas (e.g., TX) or even a fancy cup of coffee. While it is thus objectively easy to amass some wealth, numerous surveys indicate very low retirement savings for many, indeed a majority of Americans. For example, 30% of U.S. households at or near retirement age have less than $10,000 in total assets and 24% have only between $10,000 and $100,000 [14]. This means that more than one-half of retired Americans will have to live almost entirely on Social Security.

Research from a variety of fields (e.g., Evolutionary Psychology, Neuroeconomics, Behavioral Economics) and numerous authors (e.g., [15, 16]) give insight into our innate biases and strategies to effectively deal with them. Another example of a cognitive bias is "loss aversion". Research has shown that people strongly prefer avoiding losses to acquiring gains. Even capuchin monkeys show a loss aversion bias [17]. This evolved bias made sense in the ancestral context because it was better to err on the side of caution when dealing with predators, since a loss might mean death. This is sometimes referred to as the "life-dinner principle" since "it is better to miss a meal than lose your life" [13, 18]. However, this bias also results in people often being overly conservative in their investments and asset allocations over the long term and to panic in down stock markets (to "buy high, sell low"). This means that many individuals have poor long-term investment performance and thus less financial security later in life.

Sometimes evolutionary mismatches have such severe consequences that they are referred to as evolutionary traps [19, 20, 21]. The term in general has been restricted to behavioral mismatches and used for cases resulting from human-caused environmental change. It also typically has been used in reference to situations where there are potentially serious consequences to or even possible extinction of the affected species. It should be noted that there is no clear distinction

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between the term evolutionary mismatch and cases in which the mismatch is so severe that it rises to the level of an evolutionary trap. However, the term trap seems appropriate if there is a substantial reduction in evolutionary fitness [21]. An example of an evolutionary trap can be seen with albatrosses, large sea birds of the family Diomedeidae, that forage on or near the ocean surface. Today floating colored plastic is a supernormal stimulus mimicking food, and consequently albatrosses eat plastic both intentionally and sometimes accidentally in their feeding. While the adults can often regurgitate the plastic, the chicks, which are fed by their parents, cannot regurgitate. The result is that chicks are dying in large numbers [22, 23]. A totally novel, evolutionarily unprecedented aspect of its environment has thus trapped the albatross.

Another example is the ruby-throated hummingbird (*Archilochus colubris*), which faced trouble a number of years ago in parts of the midwestern United States. It feeds on nectar, especially from red flowers. But the birds also were attracted to prominent red insulators on electric fences. They would insert their beaks into the red insulators, be electrocuted, and die [24, 25]. The same attraction that has previously gotten them food, now kills them. A final nonhuman example is the jewel beetle (*Julodimorpha bakewelli*) in western Australia. This species suffered in the 1980s because of beer bottles thrown out of cars and trucks. The problem was that the bottles were orange and had dimpled surfaces, similar to the female beetles. But, the bottles were larger, more colorful, shinier, and more dimpled than the females. The males were super stimulated and would repeatedly attempt to mate with the bottles until they dried out and died or were killed by ants (Figure 2). In the meantime, females were ignored [26]. These last two examples ended well because the manufacturer changed the color of the insulators, and the beer company changed the bottle design.

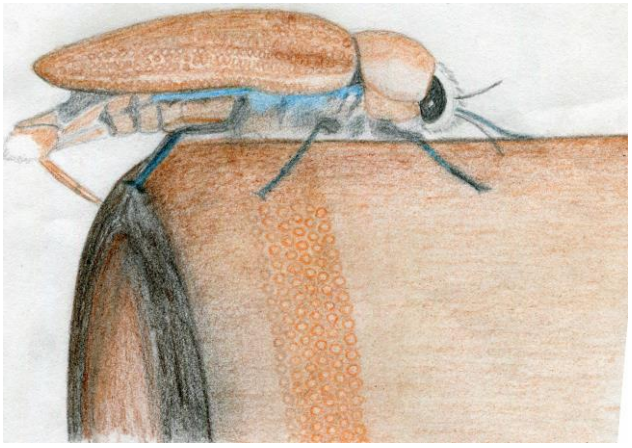

Figure 2. Jewel beetle. Drawing by Kerry Brock.

Modern humans are also being trapped in a variety of ways. An example now affecting our society is the increasing inequality in financial resources. Our innate drive to signal health, sexual vigor, and success in the modern world gets hijacked [10]. The result, due to supernormal stimuli resulting from modern advertising, sophisticated marketing, and our economic system, is that many people want and consume more and more. The end results include extreme inequality, overspending, under saving, and economic instability. Another example may be excessive bias against outsiders or those who are different. A possible evolutionary explanation might be that the most dangerous thing a hunter-gatherer band could encounter was another group of humans (due to danger from violence, competition, or exposure to parasites). Some scholars thus argue that we evolved an innate "out-group" bias or tendency towards xenophobia [10, 27-31]. In the modern world, with the potential of racial, ethnic, religious, and international conflict and even nuclear war, to fall into the trap of unrestrained "out-group" or "us versus them" bias may be

quite costly (e.g., it can trump rational voting decisions in political elections). It could be argued that an even more compelling example of an evolutionary trap is our failure to respond effectively to global climate change, with its large potential impact on the ecological support systems we and all other species rely on. Some writers suggest climate change is a uniquely difficult challenge for humans (e.g., [11, 32-37]), and that because of our cognitive biases it may be a "perfect" evolutionary trap for our species. Daniel Gilbert (in [38]) noted that "a psychologist could barely dream up a better scenario for paralysis" than climate change. Our brains evolved to focus on certain things including: 1) immediate problems and threats, particularly where there was clear danger (versus something long-term); 2) objects or events that appear suddenly or grow rapidly (versus those that are slow-moving or gradual); and 3) choices that don't require short-term sacrifice or loss (in exchange for long-term benefit) (e.g., [33]). Marshall [38] for example notes that Daniel Kahneman describes "climate change as a perfect trigger: a distant problem that requires sacrifices now to avoid uncertain losses far in the future" (which triggers our "loss aversion" bias). Climate change may also trigger our "out-group " bias because of the possibility of other countries cheating on agreed upon controls. In other words, climate change is either not sending effective alarm messages or is sending signals that run counter to our innate biases.

Given the problems caused by our cognitive biases, the question then becomes: how do we apply strategies that allow us to escape our evolutionary traps, and effectively deal with serious problems? Perhaps most importantly, if we can understand the underlying causes of these bias traps, it is possible that climate change and other long-term planning problems (e.g., retirement) can be addressed effectively. For example, in a general sense, simply by increasing awareness of and recognizing our built-in biases we may gain some measure of control. In a specific case, we can counter the "discounting the future" bias by focusing on approaches that help us connect with our future selves or with our descendants. Or we can counter "out-group" bias by employing strategies that expand group boundaries, promote intercultural exchange, increase empathy towards others, and emphasize the benefits of intergroup cooperation. Likewise, we can counter the "loss aversion" bias by appropriately framing situations (e.g. focusing on what can be gained versus lost). For example, the economic opportunities and air pollution benefits for the U.S. of developing alternative energy sources can be emphasized rather than having the focus be on perceived current costs (e.g., possible increased fossil fuel costs). Further, we can counter the "status quo" bias (tendency towards inertia/an aversion to change) by using techniques that emphasize positive change and opportunities (e.g., saving money, using less energy) (e.g. [15, 37, 39].

While many problems today seem complex or intractable, there is thus some reason to be optimistic. If we can apply evolutionarily appropriate strategies, it may be possible to make real progress addressing a number of serious problems facing us individually and as a species. As Ross et al. [39] noted, "But as history shows with regard to other shifts in norms, once the ball starts rolling, momentum can build, and remarkable change can take place quickly." It certainly seems reasonable and advisable to take action based on approaches that consider both our inherent strengths and weaknesses; this makes much more sense than continuing to be trapped like albatrosses, hummingbirds, or jewel beetles.

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